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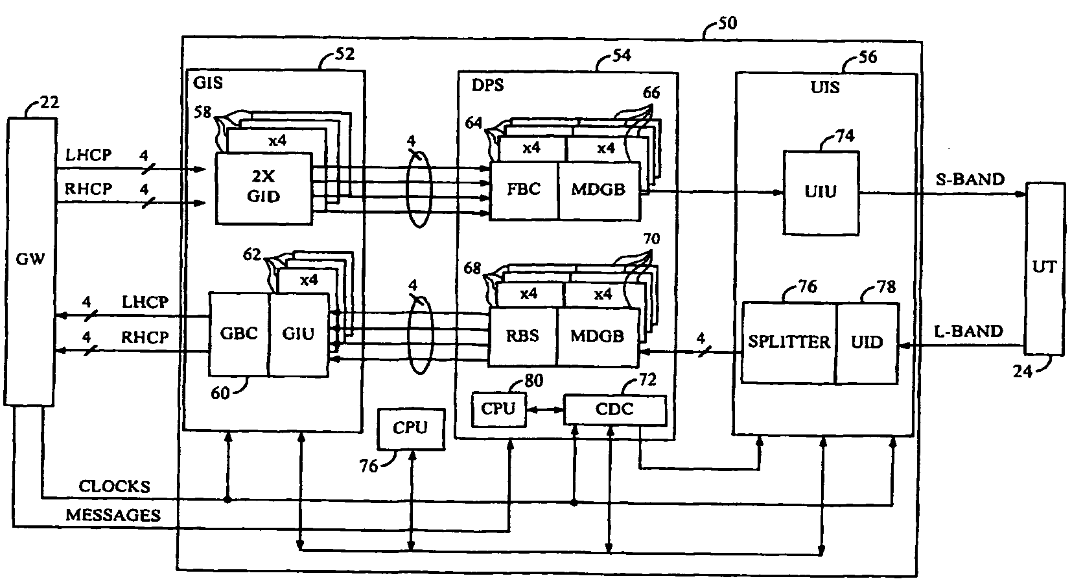

(57) Abstract: A real-time simulator (50) for a communications system (20) which includes first and second terminals (22, 24) linked via a plurality of available signal paths. The simulator (50) includes multiple parallel simulation processing channels (54), each channel modeling a respective one of the plurality of available paths (40, 42, 44, 46).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SATELLITE SIMULATOR

FIELD OF THE INVENTION

The present invention relates generally to computerized simulation and testing systems, and specifically to simulation and testing of radio communications systems.

BACKGROUND OF THE INVENTION

Satellite communications systems typically use multiple satellites to provide coverage to a wide area on the earth's surface. For example, the Globalstar system uses a constellation of 48 satellites in low earth orbits (LEO) to provide digital communications coverage worldwide. The satellites are used to connect user terminals (subscribers) anywhere in the world to terrestrial communications infrastructures via a network of fixed communications hubs, or gateways.

In order to provide full, reliable coverage, the Globalstar system is designed so that signals conveyed between a given gateway and user terminal are transmitted via up to four satellites simultaneously. These are the satellites to which a clear line-of-sight exists from both the gateway and the user terminal. Antennas on the satellite are configured so that each satellite receives and transmits signals to user terminals in its coverage area on 16 separate, but overlapping, directional beams. Each beam includes 13 sub-beams, or communication frequency channels, so that at any given moment, the gateway and user terminal may theoretically communicate over as many as 13 x 16 x 4 = 832 different channels (although in practice, far fewer channels are actually used). In the case of the Globalstar system, Code Division Multiple Access (CDMA) technology is used to enable the gateway and user terminal to decode and use the multiple-beam information.

Because of the great cost and complexity of systems such as Globalstar, there is a need to provide accurate, real-time simulation of the satellite links, so that communication routines between a gateway and user terminal can be tested without actually transmitting and receiving signals via satellites. The simulation is necessary for integration, verification, testing and debugging of the system before the satellites are

launched, as well as for analyzing problems and advanced features after deployment. Accurate simulation, however, would normally require modeling all 832 channels, each of which is characterized by different beam parameters, which vary rapidly over time due to motion of the satellites. These parameters include Doppler shift, transmission delay, gain variations, attenuation, noise and fading, as are known in the communications art. Mathematical models for simulating these effects in a single transmission channel are well known, as described, for example, in the *Communications Satellite Handbook*, by Morgan Gordon (Wiley Interscience, 1989), which is incorporated herein by reference.

Although the Globalstar system is described herein by way of example, the problems of simulating multi-channel communications are common to other satellite systems, as well as to terrestrial systems, such as cellular communications networks.

SUMMARY OF THE INVENTION

It is an object of some aspects of the present invention to provide improved equipment and methods for simulation of communications systems.

It is a further object of some aspects of the present invention to provide equipment and methods for accurate simulation of multi-channel wireless communications system with reduced cost and complexity.

It is yet another object of some aspects of the present invention to provide accurate, real-time simulation of high-speed communications systems, and particularly of satellite communications systems.

In preferred embodiments of the present invention, a real-time communications system simulator comprises multiple signal processing channels, each channel modeling a different signal path linking first and second communications terminals in a given scenario. Typically, the number of signal processing channels available in the simulator is smaller than the number of possible signal paths that may be open in the actual communications system between the first and second terminals. A path selector applies predetermined criteria to select the possible signal paths that are predicted to have the greatest significance in actual communications between the first and second terminals. The selector assigns corresponding processing channels of the simulator to model the selected paths, while non-selected paths are not modeled by the simulator. Preferably,

the simulation scenario includes dynamic changes in characteristics of the signal paths, and the selector monitors the changes and alters its assignment of the channels during simulation responsive to the changes.

The criteria for path selection and the number of paths selected are preferably determined so that only insignificant amounts of information are lost in discarding the non-selected channels. In this manner, the present invention enables highly faithful simulation of complex, multi-path communications systems, preferably in real time, while reducing the required amount of simulation hardware (and therefore size and cost). Preferably, the criterion applied to select the signal paths comprises a predicted power level of signals conveyed over each of the signal paths, and the paths having the highest predicted power levels are selected. Alternatively or additionally, the criteria may include other path characteristics, such as noise, distortion, delay, error rate or any other characteristics of relevance in the actual communications system.

In some preferred embodiments of the present invention, the system that is modeled by the simulator comprises a wireless communications system, in which the paths correspond to different beams of modulated electromagnetic energy that are transmitted and received between the first and second terminals. During the simulation, the first and second terminals are coupled to convey the beams, in the form of electromagnetic energy, to the simulator and receive the beams therefrom, rather than over the air as in the actual communications system. The selector receives the beams from the terminals and selects the beams that are to be assigned to the processing channels. Preferably, the selector comprises a beam switch for directing the energy corresponding to the selected beams to the appropriate channels. Further preferably, the simulator digitizes the selected beams from the first terminal for processing in accordance with the signal path characteristics thereof, and then converts the beams back to electromagnetic energy for output to the second terminal, and vice versa.

In one of these preferred embodiments, the system comprises a satellite communications system, wherein the first terminal comprises a gateway, or hub, and the second terminal comprises a user terminal. In actual operation of the system, signals are conveyed between the gateway and the user terminal via a plurality of satellite beams. During simulation, radio frequency (RF) inputs and outputs of the gateway and user terminal are instead linked to the simulator. The simulator calculates a simulated power level of each of the beams, taking into account the orbital motion of the satellites and

their positions relative to simulated geographic positions of the gateway and user terminal. The beam selector selects a number of the beams, preferably four beams, having the highest power levels, to be conveyed between the gateway and user terminal via the simulator. The simulated power levels are periodically re-calculated, based on the satellites' orbital motion, and the beam selector alters its selection of beams to be simulated responsive to the power levels.

In other preferred embodiments, the simulator is adapted to model other types of communications systems, such as a mobile cellular communications system, in which a user terminal (mobile station) communicates with a terrestrial network via a plurality of cells or base station transmitters. Other applications of the principles of the present invention will be apparent to those skilled in the art.

There is therefore provided, in accordance with a preferred embodiment of the present invention, a real-time simulator for a communications system, which system includes first and second terminals linked via a plurality of available signal paths. The simulator includes multiple parallel simulation processing channels, each channel modeling a respective one of the plurality of available paths in the actual communications system.

Preferably, the number of available paths is greater than the number of simulation processing channels, and the simulator includes a path selector, which applies predetermined criteria to select the paths to be modeled by the channels. Most preferably, the criteria are determined such that the selected paths are predicted to have generally the greatest significance in communications between the first and second terminals among the available paths in the actual communications system.

Further preferably, the criteria are determined such that the selected paths carry relatively larger quantities of signal energy between the first and second terminals than paths that are not selected. In a preferred embodiment, the communications system includes a wireless communications system in which the paths include a plurality of energy beams directed by the system toward one of the terminals, and the paths are selected responsive to a prediction of respective energy distribution of the beams in a vicinity of the terminal.

Preferably, the path selector alters the paths selected during operation of the simulator responsive to dynamic conditions associated with the system being simulated. Most preferably, the dynamic conditions include motion of one or more elements of the

communications system, which motion is modeled by the simulator. For each simulation processing channel, the simulator alters processing parameters used in the channel responsive to a predicted effect of the motion on the respective signal path.

Preferably, the simulator alters processing parameters used in the simulation processing channels responsive to random effects associated with the communications system.

In a preferred embodiment, the communications system includes a wireless communications system, and the simulator includes first and second ports to which the first and second terminals are respectively coupled, so as to communicate via the simulator rather than via the wireless system. Preferably, the first and second terminals communicate via multiple beams of radio frequency energy, and the simulator includes a beam switch, which switches the beams of radio frequency energy output by the first terminal into the simulation processing channels corresponding to the beams. Further preferably, the first and second terminals communicate via multiple beams of radio frequency energy, and the simulator includes a beam splitter, which splits a single beam output by the second terminal into multiple simulation processing channels corresponding to the multiple beams.

Preferably, each of the simulation processing channels is adjusted to receive and output signals at a respective frequency responsive to a communications frequency associated with the respective path. Preferably, each path has a unique frequency associated therewith. Alternatively, two or more paths may share a common frequency.

In a preferred embodiment, the communications system includes a satellite communications system including a plurality of satellites which direct the beams between the first and second terminals, and each of the simulation processing channels is assigned to correspond to one of the beams conveyed between one of the plurality of satellites and the second terminal.

Preferably, the simulation processing channels model each of the respective paths responsive to a model of orbital motion of the respective satellite. Further preferably, the assignment of each of the simulation processing channels is altered responsive to a model of orbital motion of the respective satellite, wherein when according to the model, one of the satellites passes below a predetermined elevation, the simulation processing channel assigned to the satellite is reassigned to another one of the satellites.

In a preferred embodiment, the first terminal includes a communications gateway, and the second terminal includes a user terminal.

In another preferred embodiment, the communications system includes a terrestrial communications system including a plurality of antennas which direct the beams between the first and second terminals, and wherein each of the simulation processing channels is assigned to correspond to one of the beams conveyed between one of the plurality of antennas and the second terminal. Preferably, the communications system includes a cellular communications network, and the second terminal includes a mobile user terminal, and wherein the simulation processing channels model the respective paths responsive to a model of motion of the user terminal.

Preferably, the simulation processing channels model the respective paths responsive to preprogrammed parameters associated with the paths.

There is also provided, in accordance with a preferred embodiment of the present invention, a method for real-time simulation modeling of a communications system which includes first and second terminals linked via a plurality of available signal paths, the method including:

assigning a plurality of simulation processing channels to model respective ones of the plurality of paths;

receiving signals for input to the channels; and

processing the signals in the plurality of simulation processing channels in parallel.

In a preferred embodiment, the number of available paths is greater than the number of processing channels, and assigning the channels includes selecting the paths to be modeled in accordance with predetermined criteria. Preferably, selecting the paths includes selecting paths responsive to a prediction as to which of the available paths will have generally the greatest significance in communications between the first and second terminals.

Alternatively or additionally, selecting the paths includes selecting paths calculated to carry relatively larger quantities of signal energy between the first and second terminals than non-selected paths, wherein selecting the paths includes calculating energy distributions of respective beams used to convey the signal energy over the paths.

Preferably, selecting the paths includes altering a path selection responsive to dynamic conditions associated with the system being simulated, wherein the dynamic conditions include motion of one or more elements of the system, and including modeling the motion.

In a preferred embodiment, one or more of elements of the system are in motion, and processing the signals includes modeling the motion and processing the signals responsive thereto. Preferably, the first and second terminals communicate via a plurality of satellites, and modeling the motion includes modeling orbital motion of the plurality of satellites. Additionally or alternatively, assigning the simulation processing channels includes assigning each of the simulation processing channels to correspond to a respective beam conveyed between one of the plurality of satellites and the second terminal. Preferably, assigning the simulation processing channels includes altering an assignment of one of the simulation processing channels responsive to the model of orbital motion of the respective satellite, wherein altering the assignment includes reassigning the one of the simulation processing channels when according to the model, the respective satellite passes below a predetermined elevation.

In another preferred embodiment, the second terminal includes a mobile user terminal, and wherein modeling the motion includes modeling motion of the user terminal. Preferably, the communications system includes a plurality of antennas coupled to the first terminal, and assigning the simulation processing channels includes assigning each of the simulation processing channels to correspond to a beam conveyed between the user terminal and a respective one of the antennas.

Preferably, receiving the signals includes receiving a signal from the first terminal, and including outputting the processed signals to the second terminal. Most preferably, receiving the signals includes receiving a radio frequency signal, and processing the signals includes digitizing the radio frequency signal, wherein receiving the radio frequency signal includes receiving multiple radio frequency signals, and wherein processing the signals includes switching the signals so as to convey each of the multiple signals to the assigned simulation processing channel. Additionally or alternatively, processing the signals includes splitting the signal among multiple processing channels.

Preferably, processing the signals includes processing signals in the simulation processing channels responsive to random effects associated with the respective paths.

Alternatively or additionally, processing the signals includes processing signals in the simulation processing channels responsive to preprogrammed simulation parameters.

The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of a satellite communications system including multiple beam paths, which are modeled by simulation, in accordance with a preferred embodiment of the present invention;

Fig. 2 is a schematic block diagram of a multiple-path simulator, in accordance with a preferred embodiment of the present invention;

Fig. 3 is a schematic block diagram showing details of a forward link in the simulator of Fig. 2;

Fig. 4 is a schematic block diagram showing details of a reverse link in the simulator of Fig. 2;

Fig. 5 is a flow chart illustrating a method of switching simulated beams in the simulator of Fig. 2, in accordance with a preferred embodiment of the present invention;

Fig. 6 is a flow chart illustrating a state machine used in carrying out the method of Fig. 5, in accordance with a preferred embodiment of the present invention; and

Fig. 7 is a schematic block diagram of a multiple-path simulator, in accordance with another preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1 is a schematic illustration showing elements of a satellite communications system 20 that are modeled by simulation, in accordance with a preferred embodiment of the present invention. The system shown in the figure is based generally on the Globalstar LEO satellite system, as described in the Background of the Invention. It comprises a gateway (GW) 22 and a user terminal (UT) 24, which communicate via multiple beams 38. For the sake of clarity in the figure and the description that follows, only the paths of beams 40, 42, 44 and 46 are shown. Although real-time

communications simulators are known in the art, they are typically capable of simulating only a single, predetermined beam path. Simulation of all of beams 38, which would be required for fully accurate modeling of system 20, is prohibitively cumbersome and costly.

Gateway 22 outputs RF modulated signals, preferably at an intermediate-frequency (IF) of about 900 MHz, to a converter 26, which up-converts the IF signals to a higher radio frequency for transmission via satellites 28, 30, 32 and 34. The converter also down-converts RF signals received from the satellites. Typically, gateway 22 is coupled to converter 26 by sixteen IF feeder links: eight links for forward channels transmitted to UTs, and eight for reverse channels from the UTs. Each pair of links (one for right-hand and one for left-hand circularly polarized signals) is capable of carrying 208 CDMA frequency channels, having standard channel bandwidths of 1.23 MHz, which are transmitted via one of the satellites. UT 24 receives RF signals at S-band frequencies (about 2500 MHz) and transmits signals back to the gateway at L-band frequencies (about 1600 MHz). These frequency values and numbers of channels are cited by way of example, however, and the present invention is not in any way limited by such aspects of the system configuration.

The satellites retransmit the signals received from converter 26 to UT 24 in beams 38. The beams are formed and directed by the satellites so that each beam is aimed at a different angle, and together they cover a substantial area on the earth's surface. The beams overlap, however, and each beam typically spreads over an area substantially beyond its nominal design coverage. Therefore, UT 24 can receive at least some RF energy from substantially all of beams 38. Preferably, CDMA technology used in system 20 enables UT 24 to extract information from a substantial number of the beams that the UT receives.

Because satellites 28, 30, 32 and 34 orbit the earth in non-geosynchronous orbits, the position of the satellites relative to gateway 22 and UT 24 changes rapidly. The different positions of the satellites and their motion relative to the gateway and UT result in each beam having a different transmission delay and Doppler shift associated therewith. The Doppler shift further varies from beam to beam as a function of the beam frequency. The beams also have different gain and fade characteristics, due to geometrical and atmospheric factors, and pick up noise from various sources, including white noise, thermal noise and correlated noise (such as cross-talk). Furthermore, as

each of the satellites continues in its orbits, it eventually sets over the horizon relative to gateway 22 and UT 24. Thus, for example, communication paths, such as beam 40, between the gateway and the UT via satellite 28 will cease to function as satellite 28 sets below the horizon. In their stead, communication paths will open up via a new satellite 36, which rises over the horizon.

Fig. 2 is a schematic block diagram illustrating a simulator 50, used in modeling system 20, in accordance with a preferred embodiment of the present invention. Simulator 50 is configured so as to be capable of modeling all of the dynamic aspects of the operation of system 20 that are described hereinabove. The simulator may also be programmed, however, to model only a subset of these dynamic aspects, or to run a non-physical model, i.e., a model that does not strictly correspond to the expected behavior of an actual communications system. Although simulator 50 is typically programmed for simulation based on the expected motion of a satellite or other vehicle in the system being modeled, the simulator may be operated in accordance with substantially any suitable set of parameters, either deterministic or random.

Preferably, simulator 50 links an actual gateway 22 and an actual UT 24, as are used in system 20. On the forward link, the simulator is configured to receive the eight IF forward channels from gateway 22, and then to digitize, process and combine the signals, and convert the result to an S-band RF signal for output to UT 24. On the reverse link, the simulator receives an L-band input from the UT, and digitizes, processes and splits the signal into eight IF signals for output to the gateway. As described in greater detail hereinbelow, simulator 50 does not model all of the possible satellite beams connecting the gateway and the UT, but rather dynamically selects and processes only the beams that would (under actual operating conditions of system 20) carry the greatest amount of energy between the gateway and the UT.

Simulator 50 comprises three major subsystems:

- Gateway Interface Shelf (GIS) 52;
- Digital Processing Shelf (DPS) 54; and
- User Terminal Interface Shelf (UIS) 56.

The details and functions of these subsystems are described hereinbelow with reference to forward- and reverse-link processing modes of the simulator.

DPS 54 is preferably built around an industry-standard computer, such as an industrial-grade personal computer (PC), with special-purpose processing boards

plugged into its bus slots. The DPS includes a CPU 80, such as an Intel Pentium processor, on which software runs to control functions of simulator 50, and a clock distribution card (CDC) 72, which distributes system clock and control instructions to the subsystems of the simulator. CPU 80 tracks the positions of the satellites in a simulation scenario, using Kepler's equations or other methods of orbital modeling known in the art, and periodically issues operational parameters based on the orbital modeling to the other elements of the simulator. Preferably, the CPU calculates and outputs new parameters approximately every 1.25 ms.

Fig. 3 is a block diagram illustrating details of forward link operation of simulator 50. The eight IF input lines from gateway 22 are split by GIS 52 among eight Gateway Interface Downconverter (GID) cards 58. Each of the four pairs of GIDs preferably receives the IF signals that are designated for a particular one of the four satellites by way of which gateway 22 and user terminal 24 are meant to be communicating in a given simulation scenario. Out of the 104 CDMA sub-beams (8 beams x 13 frequency channels, as described hereinabove) that it receives from the respective input line, each GID down-converts two separate, parallel sub-beams from the 900 MHz input frequency range to a lower IF range of 4.9 ± 0.6 MHz. Preferably, the GIS also applies simulated backhaul attenuation losses to the signals in both the forward and reverse links.

Each GID 58 selects its respective sub-beams for down-conversion based on instructions received from CDC 72 in DPS 54. The CDC receives selection instructions from CPU 80. The sub-beams selected at any moment are those which are estimated by the CPU, based on the satellite's computed position, to be the ones that carry the greatest amount of signal energy via the particular satellite between gateway 22 and UT 24.

Each of the selected sub-beams is assigned to one of sixteen processing channels, four channels on each of the four FBCs 64 in DPS 54. Each of the FBCs thus receives four analog IF inputs from a corresponding pair of GIDs 58, preferably so as to model four beams associated with one of the four satellites. Alternatively, different allocations may be made of the GIDs and FBCs, so as to simulate, for example, eight beams of each of two satellites or sixteen beams of a single satellite. Other combinations are also possible, and simulator 50 may also be configured to model more or fewer than sixteen channels, by adding or removing hardware as appropriate.

Each FBC 64 digitizes the input IF beams and then digitally filters and down-converts its four input signals to baseband. For each beam, the FBC applies appropriate beam-specific Doppler phase rotation and gain parameters, to account for the particular C-band frequency of the beam. Then all of the beams from a single satellite, which have been processed on one or more of the FBCs, are combined and passed to one of the Main Digital Processing Boards (MDGB) 66.

The MDGB applies processing functions corresponding to the effects of the satellite's position and motion, in common to all of the beams transmitted via that satellite. These effects include transmission delay, Doppler shift, fading, attenuation and additive noise, typically comprising white Gaussian noise, as well as due to thermal noise and the effect of other satellite signals. Preferably, the delay is introduced using a synchronous delay generator, as described in the patent application entitled "Satellite Motion Simulator" filed August 31, 1999, as our docket PA878, serial no.________, incorporated herein by reference.

The processed outputs of the four MDGBs 66 are summed together to give a single digital datastream, which is then upconverted and filtered to give a 12-bit IF digital signal, preferably at about 4.9 MHz. The digital IF signal is conveyed to UIS 56, wherein a UT Interface Upconverter (UIU) 74 converts it to analog form and up-converts it to S-band for output by cable to UT 24. Alternatively, if a UT with multiple antennas is used, the processed outputs of the four MDGBs may be separately upconverted and converted to RF analog signals by optional parallel channels in UIS 56 (not shown in the figures). The output of each of the parallel channels is preferably connected to a respective one of the UT antennas.

Fig. 4 is a block diagram illustrating details of reverse link operation of simulator 50. UT 24 outputs an L-band (1610-1626.5 MHz) signal, which is received via cable by UIS 56. A UT Interface Downconverter (UID) 78 down-converts the signal to 4.9 MHz and digitizes it. The digital signal is split into four identical replicas by a splitter 76, which feeds the signals to four MDGBs 70 in DPS 54. As in the forward link, each MDGB 70 represents and simulates the effects of a single satellite. The MDGB converts the digital IF signals to baseband, and then processes the signals responsive to the effects of delay, Doppler shift, fading attenuation and thermal noise, based on the computed position and motion of the satellite.

For each MDGB, a Reverse Beamsplitter (RBS) 68 splits the signal into four separate streams, each corresponding to one of the beams of the respective satellite. Although the satellites to be modeled by MDGBs 70 and RBSs 68 for the reverse link are typically the same ones that are chosen to be modeled on the forward link, the beams are generally different. For each beam, the RBS multiplies the digital signal by the appropriate attenuation parameter and adds filtered and correlated noise (engendered due to the other beams). The resulting signal for each beam is phase-rotated to account for the difference in Doppler shift between the different beams of the same satellite, as well as to fine-tune the frequency for upconversion. Finally, the signals are upconverted to about 4.9 MHz, filtered and converted to analog form for output to GIS 52.

GIS 52 comprises four Gateway Interface Up-converters 62, each of which combines the four output signals from a corresponding one of the RBSs and up-converts the signals to about 900 MHz, in two output beams with right-hand and left-hand circular polarity, respectively. A GIS Block Converter (GBC) 60 up-converts the signals to a final output frequency of about 2.185 ±0.1 GHz and conveys the signals via eight output lines to GW 22.

Fig. 5 is a flow chart, illustrating a method by which CPU 80 controls assignment of the simulation channels in simulator 50, in accordance with a preferred embodiment of the present invention. Preferably, the CPU continuously tracks the positions of the satellites used in the simulation model and issues instructions to the elements of GIS 52 and DPS 54 when it is necessary to change the beam or satellite being modeled by one of the sixteen simulation channels. As in real-world communications systems, such as system 20 (Fig. 1), whenever a satellite drops below 10^{o} above the horizon, it is dropped from the simulation and replaced by a new satellite. Simulator 50 also allows fault situations, such as unavailability of a satellite or beam, to be modeled in similar fashion.

Thus, when satellite 28 is dropped, CPU 80 calculates the position of new satellite 36, and downloads the relevant parameters and settings to the simulation hardware. During the download (as in the real world), data flow is shut off through the simulation channels corresponding to the satellite being replaced. Typically these channels cover one of the four sets of GIDs 58, FBCs 64 and MDGBs 66 in the forward link, and a corresponding set of the MDGBs 70, RBSs 68 and GIUs 62 in the reverse link. Data flow is meanwhile allowed to proceed only through the channels modeling

the three remaining satellites. The flow through the fourth channel resumes after the hardware has received its new satellite assignment, and after the new satellite has risen by a simulated 10^o above the opposite horizon. In simulation of the Globalstar system, such satellite switching occurs about once every five minutes.

Among the sixteen directional beams relayed by each satellite, for each of the forward and reverse directions, CPU 80 preferably chooses to simulate the four "strongest" beams, i.e., those beams calculated to convey the greatest signal energy between gateway 22 and UT 24, in the four simulation channels allocated to the satellite. The calculation for each beam is based on the position of the UT relative to the beam energy pattern on the ground, or footprint, and the estimated geometrical attenuation of the beam. Periodically, CPU 80 compares the strength of the beams currently being simulated to that of other, non-simulated beams. When it is determined that one of the current beams is substantially weaker than a non-simulated beam, preferably by at least 0.5 dB, the CPU drops the weaker beam from its assigned simulation channel and assigns the new, stronger beam to the channel.

The beam attenuation values are preferably estimated to a resolution of about 1^o, so that a new beam is typically evaluated for selection approximately once every five seconds, and the beams are switched roughly once per minute on average. This process is carried out separately for the forward and reverse directions. CPU 80 preferably checks the beam strengths every 125 ms. When the CPU decides to switch beams, the simulation channel assigned to the weak beam is shut off, preferably on the pulse of one 125 ms clock "tick." The frequency downconverter (in the corresponding forward link channel) or the upconverter (in the reverse link channel) is adjusted for the frequency of the new beam. The channel is preferably reopened at the next clock tick. All of the other forward and reverse channels continue to operate during the switchover. Since the weak beam that is dropped and the stronger beam replacing it are typically weaker than any of the remaining three beams, there is little effect on the accuracy of simulation during the single tick that the one channel is shut off.

Whenever the beam assigned to one of the simulation channels is to be switched, CPU 80 preferably carries out the following steps:

- <u>Forward link –</u>
    - Switch gain to zero in the corresponding FBC 64.

- Set parameters in the corresponding GID 58, including LHCP/RHCP selection of the new beam, backhaul loss attenuation and downconverter frequency.
- Download fine frequency correction and fine (beam-specific) Doppler phase rotation to FBC 64.
- Check that synthesizers in GID 58 are locked to the frequency of the new beam.
- Switch gain to the new value for the channel, enabling the new beam to pass through at the appropriate gain.

- <u>Reverse link –</u>
  - Switch beam off in the corresponding RBS 68, preferably by setting a data bit dedicated for this purpose.
  - Set parameters in the corresponding GIU 62, including upconverter frequency, backhaul loss attenuation and LHCP/RHCP selection of the new beam.
  - Download fine frequency correction and fine (beam-specific) Doppler phase rotation to RBS 68.
  - Load correlation matrix to RBS 68 for calculating correlated noise based on the new beam configuration.
  - Check that synthesizers in GIU 62 are locked to the frequency of the new beam.
  - Download new gain value and switch beam on in RBS 68.

Fig. 6 is a flow chart illustrating a state machine 90 used in selecting which of the beams associated with a particular satellite to simulate, in accordance with a preferred embodiment of the present invention. The state machine is maintained separately for each of the beams and is used by CPU 80 to keep track of the simulation status of the beam. The state machine information is used together with estimation of the strength of each of the simulated beams in deciding which beams to select for simulation.

Four states are defined for each beam:

- Dummy tick 92, in which the simulation awaits confirmation that an antenna link has been established by the satellite associated with the beam, or when the beam is otherwise not in use by the simulation.
- Initialization tick 94, in which a channel is assigned to the beam, and the CPU sets and downloads the parameters for simulating the beam using the particular channel.
- Regular tick 96, in which the simulation is running, and parameters such as Doppler shift, delay and gain are updated.
- Beam switch tick 98, which is entered when the process of switching beams is initiated for one of the channels.

All of the simulated beams begin in dummy tick 92 and revert to this state whenever the satellite antenna link is broken, as indicated in the figure, or when the beam is unused. When the antenna link is valid and the beam is selected for simulation by one of the simulator channels, the beam is assigned to initialization tick 94 for a single cycle of a simulation clock maintained by CPU 80. The beam is then maintained in regular tick 96 for as long as the simulation proceeds normally.

Whenever the CPU determines that the beam assigned to one of the simulation channels should be switched, all of the simulated beams enter beam switch tick 98. The determination may be made because the simulated beams are no longer the strongest beams available, or because one or more of the beams have become unavailable for some reason. In deciding which beams to simulate at a beam switch, the CPU selects the four strongest beams for the given satellite (or eight, if eight beams are being simulated) that are available for simulation and are in a suitable state of state machine 90, preferably in initialization tick 94. The CPU then compares these four strongest beams with the four beams that are currently being simulated. If one of the simulated beams is not included among the selected beams, it is replaced by the one of the selected beams that is not currently simulated. Typically, although not necessarily, at any beam switch, only one of the beams is replaced.

Although the preferred embodiment described hereinabove makes reference to simulation of a particular, satellite-based communications system, those skilled in the art will appreciate that the principles of the present invention may similarly be applied to simulate other complex communications systems, including both wireless and cable-based systems. In particular, the principles of multi-channel simulation described herein

may be applied in the simulation of cellular communications systems, in which multiple base station transmitters communicate with a mobile user terminal, typically over multiple paths.

Fig. 7 is a schematic block diagram illustrating a simulator 120 for use in modeling such a cellular communications system, in accordance with a preferred embodiment of the present invention. Simulator 120 links a base station subsystem 122, comprising a base station controller (BSC) and base station transceiver (BTS), with a user terminal (UT) 124, preferably comprising a cellular telephone 126. BSC/BTS 122 typically comprises a plurality of directional antennas 128, which serve a plurality of respective sectors.

On the forward link, simulator 120 is coupled to receive RF signals from BSC/BTS 122 via a back-end RF interface 130. The signals are digitized and then processed by a digital channel board (DCB) 132 in up to four different transmission channels. Each such channel models a different beam path that would exist in the actual cellular system, between one of antennas 128 and UT 124. The digitized signals in each of the channels are processed to simulate such effects as noise, fading, attenuation, delay and Doppler shift associated with the corresponding beam, based on a model of expected motion of the UT (such as traveling in an automobile). The principles of the simulation are generally similar to those described above with reference to simulator 50, although the implementation is adapted for the conditions of terrestrial, cellular communications, rather than satellite communications. The four transmission channel outputs of DCB 132 are converted back to RF signals by a front-end RF interface 134 and are then combined by an RF splitter/combiner 136 for output to UT 124.

On the reverse link of the simulator, RF signals output by UT 124 are split into multiple channels, corresponding to the multiple beam paths back to antennas 128 of BSC/BTS 122 by splitter/combiner 136. The signals are then input to DCB 132 via front-end RF interface 134. The DCB includes eight channels for processing reverse-link signals (Rx_0 and Rx_1), corresponding to two reverse beams for each sector (i.e., for each one of antennas 128). The processed signals are then output via back-end RF interface 130 to BSC/BTS 122.

Simulator 120 also offers the possibility of testing communications between BSC/BTS 122 and UT 124 using digital signals, without passing through RF interfaces 130 and 134. This type of simulation testing has the advantage of enabling circuit

components and software to be evaluated substantially independently of any effects introduced by RF modulation and demodulation of signals between the BSC/BTS and UT. For this purpose, BSC/BTS 122 is coupled via an RF/digital interface 140 to a digital board 138. Another RF/digital interface 142 couples the digital board to UT 124 via RF splitter/combiner 136. RF/digital interfaces 140 and 142 are coupled directly to internal, digital components or ports of BSC/BTS 122 and UT 124 (generally by a suitable connector or patch provided for this purpose). Interfaces 140 and 142 perform digital emulation of the actual RF interfaces in the communications system.

A simulator control unit 144 provides synchronization and control signals to the other elements of simulator 120 and exchanges simulation data therewith. Control unit 144 can be programmed using a remote control unit 146, preferably comprising a personal computer, or via a computer network. The control unit can also be coupled to off-shelf test equipment 148, for evaluating the performance of the simulator.

Simulator 120 can also be adapted to test the performance of BSC/BTS 122 (and of other elements of the cellular system to which the BSC/BTS belongs) while conducting multiple calls simultaneously. For this purpose, a rack 150 including a plurality of UTs 152 is coupled to the simulator via an adjustable RF gain matrix 154, which directs signals between the BSC/BTS and the UTs. Additional DCBs 132 may be added to simulator 120 to accommodate the additional communications channels.

It will be thus be understood that the preferred embodiments described above are cited by way of example, and the full scope of the invention is limited only by the claims.

CLAIMS

1. A real-time simulator for a communications system which system includes first and second terminals linked via a plurality of available signal paths, the simulator comprising multiple parallel simulation processing channels, each channel modeling a respective one of the plurality of available paths.

2. A simulator according to claim 1, wherein the number of available signal paths in the communications system is greater than the number of simulation processing channels, and comprising a path selector, which applies predetermined criteria to select the signal paths to be modeled by the simulation processing channels.

3. A simulator according to claim 2, wherein the criteria are determined such that the selected signal paths are predicted to have generally the greatest significance in communications between the first and second terminals among the available signal paths in the actual communications system.

4. A simulator according to claim 2, wherein the criteria are determined such that the selected signal paths carry relatively larger quantities of signal energy between the first and second terminals than paths that are not selected.

5. A simulator according to claim 4, wherein the communications system comprises a wireless communications system in which the signal paths comprise a plurality of energy beams directed by the system toward one of the terminals, and wherein the paths are selected responsive to a prediction of respective energy distribution of the beams in a vicinity of the terminal.

6. A simulator according to claim 2, wherein the path selector alters the paths selected during operation of the simulator responsive to dynamic conditions associated with the system being simulated.

7. A simulator according to claim 6, wherein the dynamic conditions comprise motion of one or more elements of the communications system, which motion is modeled by the simulator.

8. A simulator according to claim 7, wherein for each simulation processing channel, the simulator alters processing parameters used in the channel responsive to a predicted effect of the motion on the respective signal path.

9. A simulator according to claim 1, wherein the simulator alters processing parameters used in the simulation processing channels responsive to random effects associated with the communications system.

10. A simulator according to claim 1, wherein the communications system comprises a wireless communications system, and wherein the simulator comprises first and second ports to which the first and second terminals are respectively coupled, so as to communicate via the simulator rather than via the wireless system.

11. A simulator according to claim 10, wherein the first and second terminals communicate via multiple beams of radio frequency energy, and comprising a beam switch, which switches the beams of electromagnetic energy output by the first terminal into the simulation processing channels corresponding to the beams.

12. A simulator according to claim 10, wherein the first and second terminals communicate via multiple beams of electromagnetic energy, and comprising a beam splitter, which splits a single beam output by the second terminal into multiple simulation processing channels corresponding to the multiple beams.

13. A simulator according to claim 10, wherein each of the simulation processing channels is adjusted to receive and output signals at a respective frequency responsive to a communications frequency associated with the respective path.

14. A simulator according to claim 10, wherein the communications system comprises a satellite communications system including a plurality of satellites which direct the beams between the first and second terminals, and wherein each of the simulation processing channels is assigned to correspond to one of the beams conveyed between one of the plurality of satellites and the second terminal.

15. A simulator according to claim 14, wherein the simulation processing channels model each of the respective paths responsive to a model of orbital motion of the respective satellite.

16. A simulator according to claim 15, wherein the assignment of each of the simulation processing channels is altered responsive to a model of orbital motion of the respective satellite.

17. A simulator according to claim 16, wherein when according to the model, one of the satellites passes below a predetermined elevation, the simulation processing channel assigned to the satellite is reassigned to another one of the satellites.

18. A simulator according to claim 14, wherein the first terminal comprises a communications gateway, and the second terminal comprises a user terminal.

19. A simulator according to claim 10, wherein the communications system comprises a terrestrial communications system including a plurality of antennas which direct the beams between the first and second terminals, and wherein each of the

simulation processing channels is assigned to correspond to one of the beams conveyed between one of the plurality of antennas and the second terminal.

20. A simulator according to claim 19, wherein the communications system comprises a cellular communications network.

21. A simulator according to claim 19, wherein the second terminal comprises a mobile user terminal, and wherein the simulation processing channels model the respective paths responsive to a model of motion of the user terminal.

22. A simulator according to claim 1, wherein the simulation processing channels model the respective paths responsive to preprogrammed parameters associated with the paths.

23. A method for real-time simulation modeling of a communications system which includes first and second terminals linked via a plurality of available signal paths, the method comprising:

assigning a plurality of simulation processing channels to model respective ones of the plurality of paths;

receiving signals for input to the channels; and

processing the signals in the plurality of simulation processing channels in parallel.

24. A method according to claim 23, wherein the number of available paths is greater than the number of processing channels, and wherein assigning the channels comprises selecting the paths to be modeled in accordance with predetermined criteria.

25. A method according to claim 24, wherein selecting the paths comprises selecting paths responsive to a prediction as to which of the available paths will have generally the greatest significance in communications between the first and second terminals.

26. A method according to claim 24, wherein selecting the paths comprises selecting paths calculated to carry relatively larger quantities of signal energy between the first and second terminals than non-selected paths.

27. A method according to claim 26, wherein selecting the paths comprises calculating energy distributions of respective beams used to convey the signal energy over the paths.

28. A method according to claim 24, wherein selecting the paths comprises altering a path selection responsive to dynamic conditions associated with the system being simulated.

29. A method according to claim 28, wherein the dynamic conditions comprise motion of one or more elements of the system, and comprising modeling the motion.

30. A method according to claim 23, wherein one or more of elements of the system are in motion, and wherein processing the signals comprises modeling the motion and processing the signals responsive thereto.

31. A method according to claim 30, wherein the first and second terminals communicate via a plurality of satellites, and wherein modeling the motion comprises modeling orbital motion of the plurality of satellites.

32. A method according to claim 31, wherein assigning the simulation processing channels comprises assigning each of the simulation processing channels to correspond to a respective beam conveyed between one of the plurality of satellites and the second terminal.

33. A method according to claim 32, wherein assigning the simulation processing channels comprises altering an assignment of one of the simulation processing channels responsive to the model of orbital motion of the respective satellite.

34. A method according to claim 33, wherein altering the assignment comprises reassigning the one of the simulation processing channels when according to the model, the respective satellite passes below a predetermined elevation.

35. A method according to claim 30, wherein the second terminal comprises a mobile user terminal, and wherein modeling the motion comprises modeling motion of the user terminal.

36. A method according to claim 35, wherein the communications system comprises a plurality of antennas coupled to the first terminal, and wherein assigning the simulation processing channels comprises assigning each of the simulation processing channels to correspond to a beam conveyed between the user terminal and a respective one of the antennas.

37. A method according to claim 23, wherein receiving the signals comprises receiving a signal from the first terminal, and comprising outputting the processed signals to the second terminal.

38. A method according to claim 23, wherein receiving the signals comprises receiving a radio frequency signal, and wherein processing the signals comprises digitizing the radio frequency signal.

39. A method according to claim 38, wherein receiving the radio frequency signal comprises receiving multiple radio frequency signals, and wherein processing the

signals comprises switching the signals so as to convey each of the multiple signals to the assigned simulation processing channel.

40. A method according to claim 38, wherein processing the signals comprises splitting the signal among multiple processing channels.

41. A method according to claim 23, wherein processing the signals comprises processing signals in the simulation processing channels responsive to random effects associated with the respective paths.

42. A method according to claim 23, wherein processing the signals comprises processing signals in the simulation processing channels responsive to preprogrammed simulation parameters.

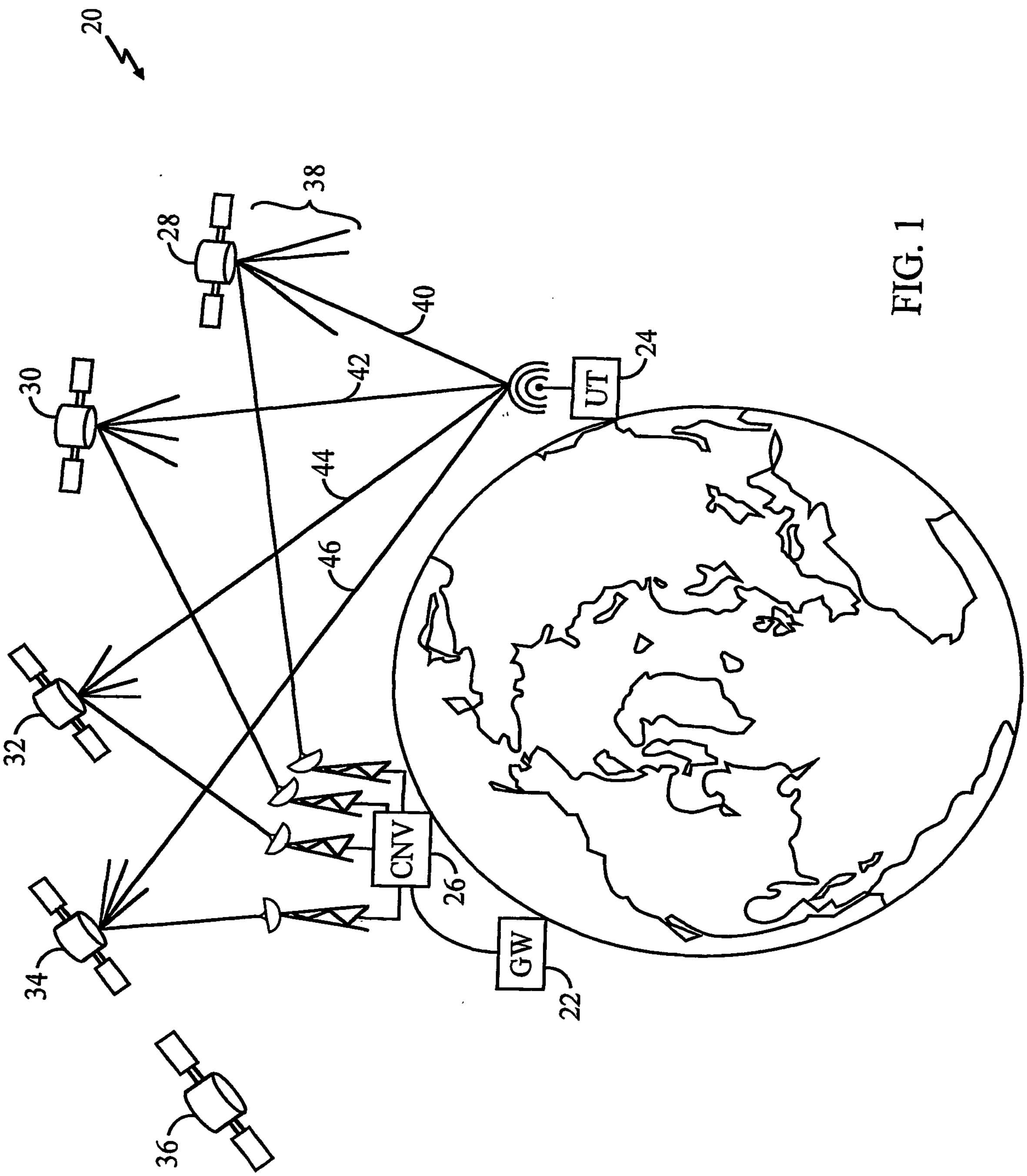

FIG. 1

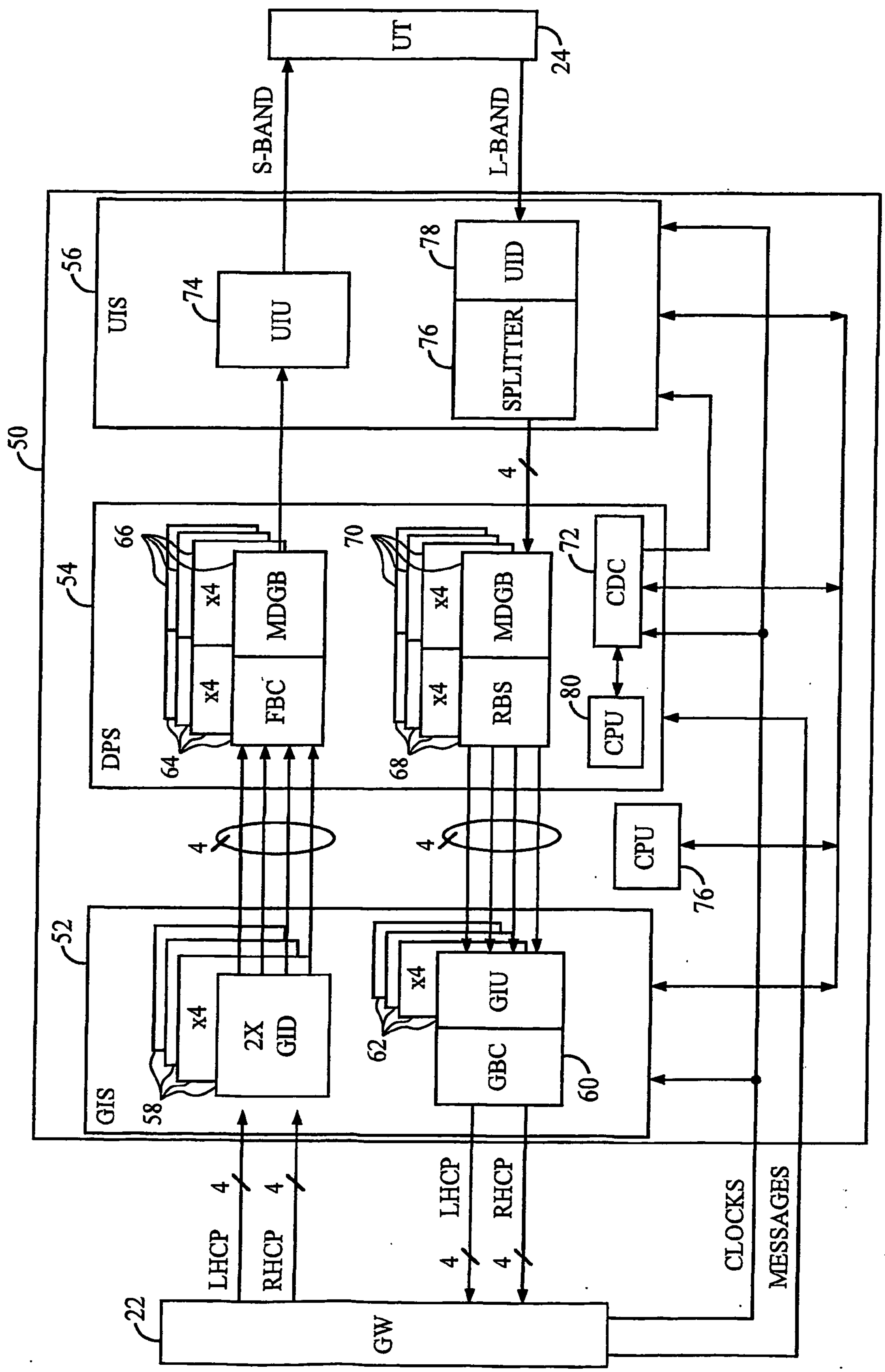

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FIG. 2

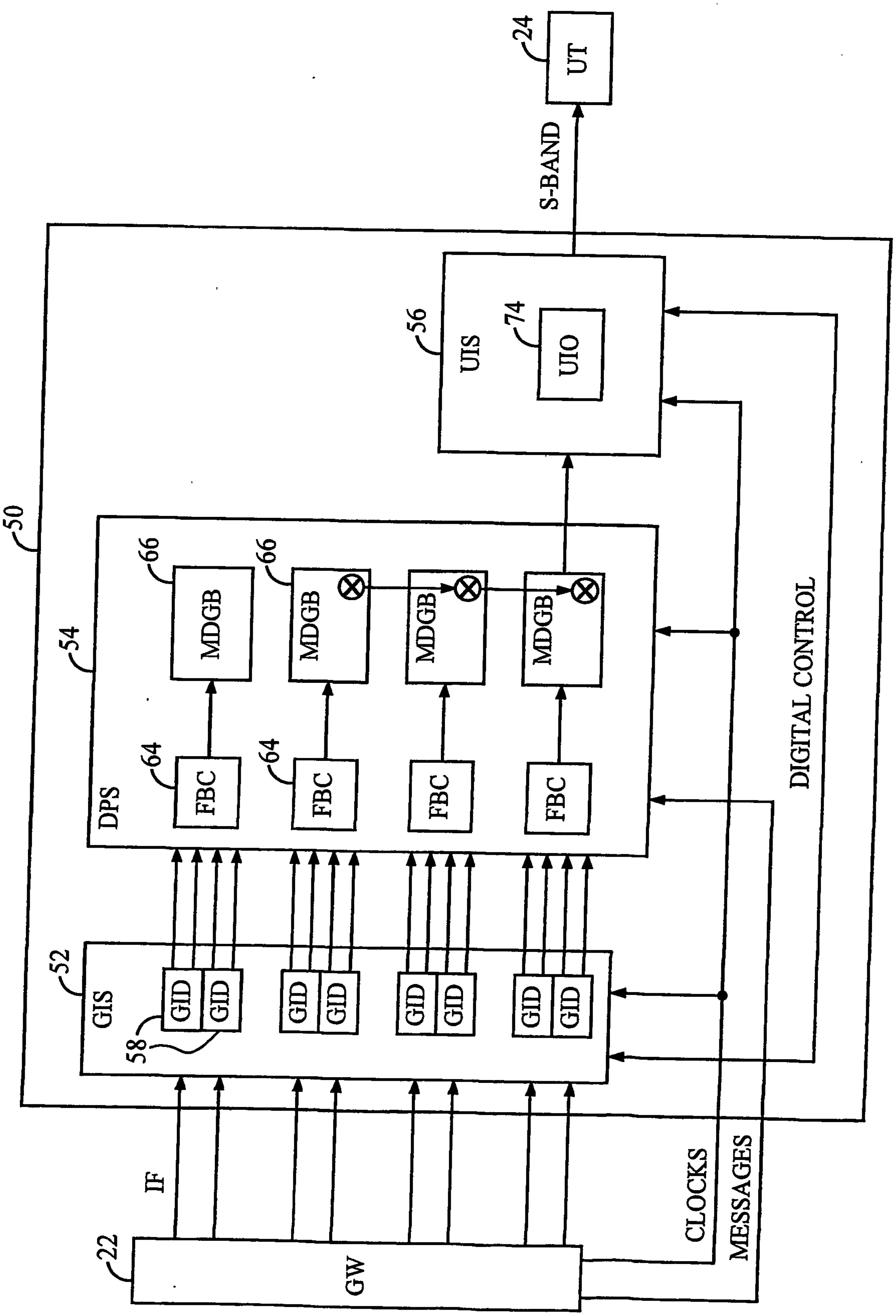
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FIG. 3

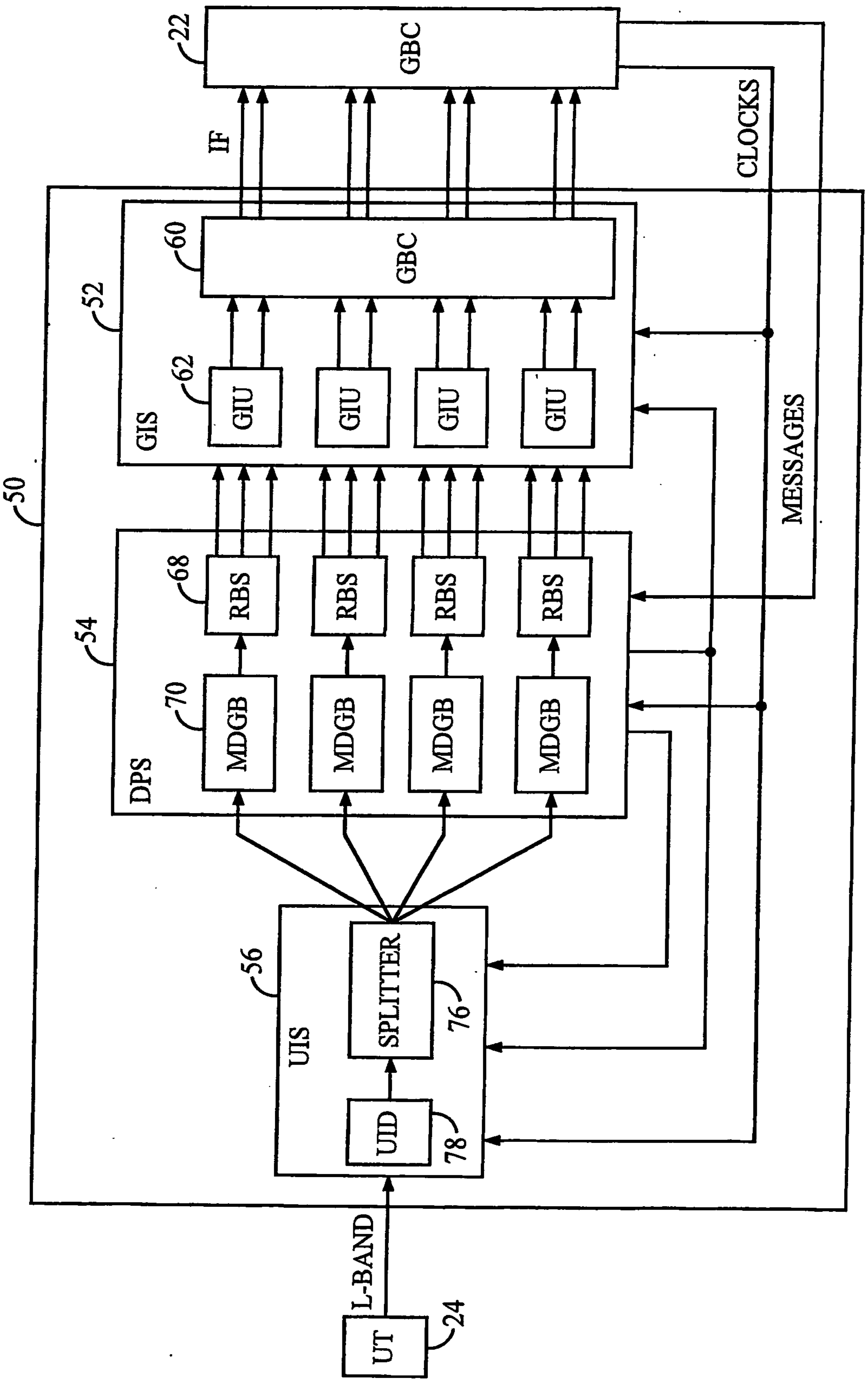
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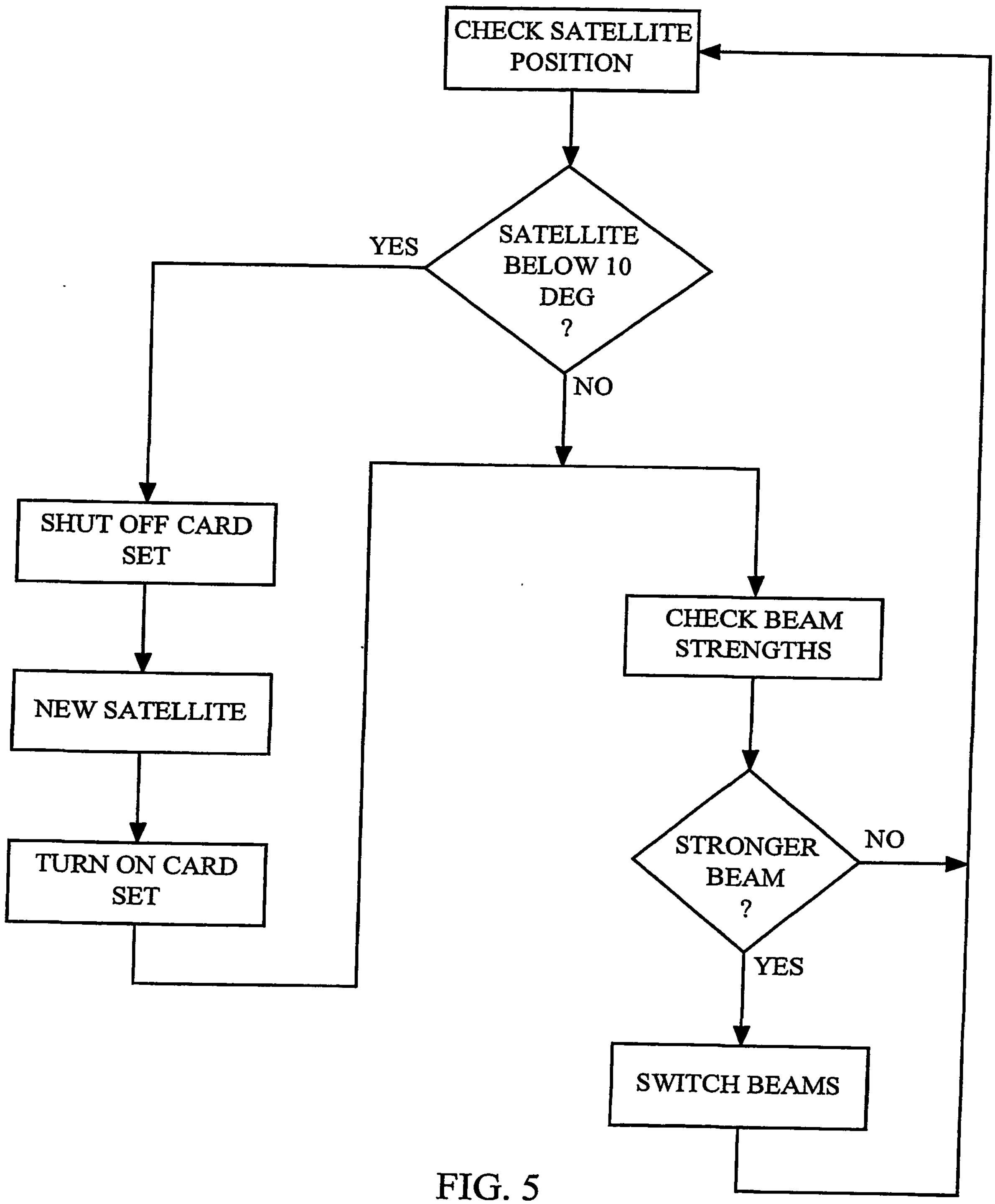
FIG. 4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YES
SWITCH BEAMS

FIG. 5

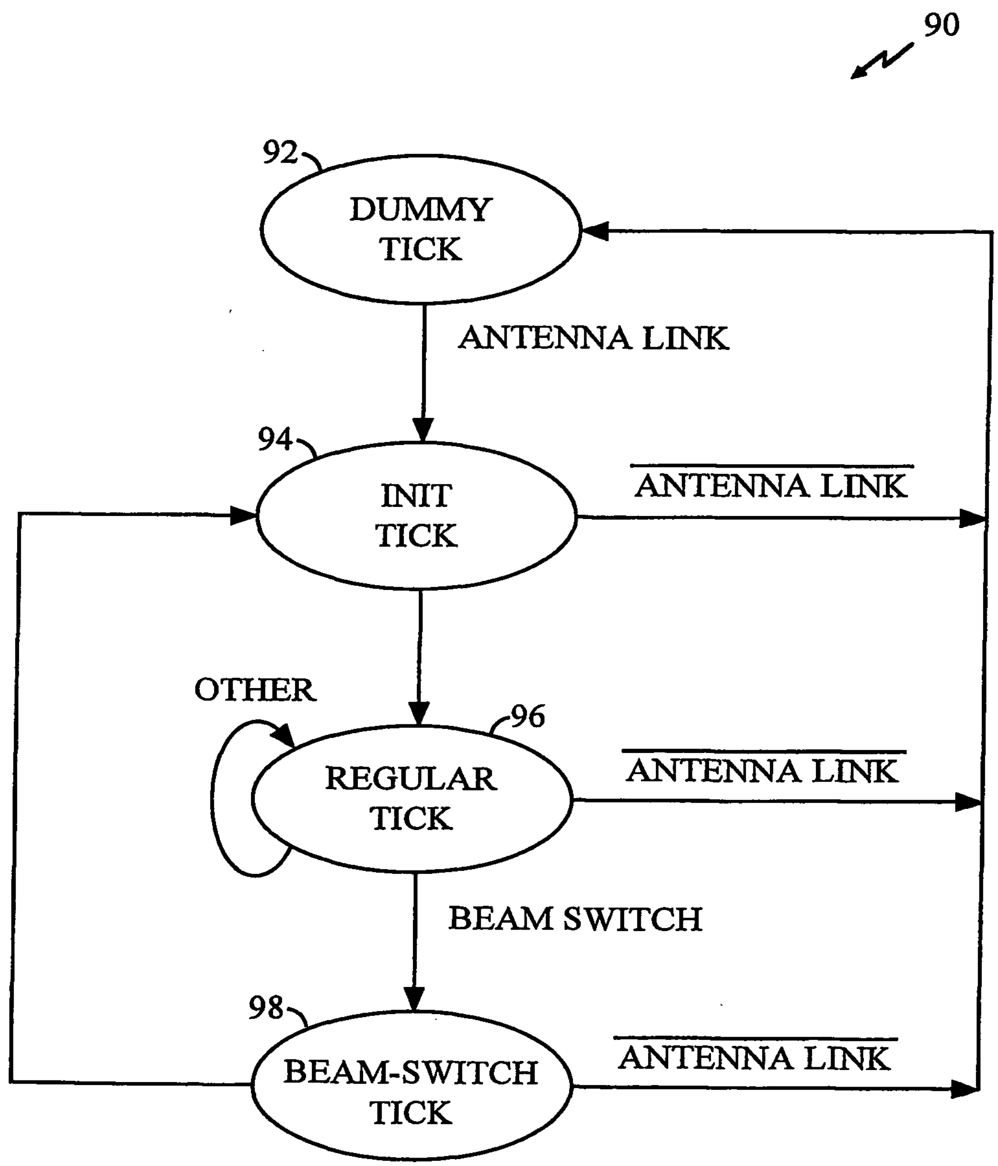
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FIG. 6

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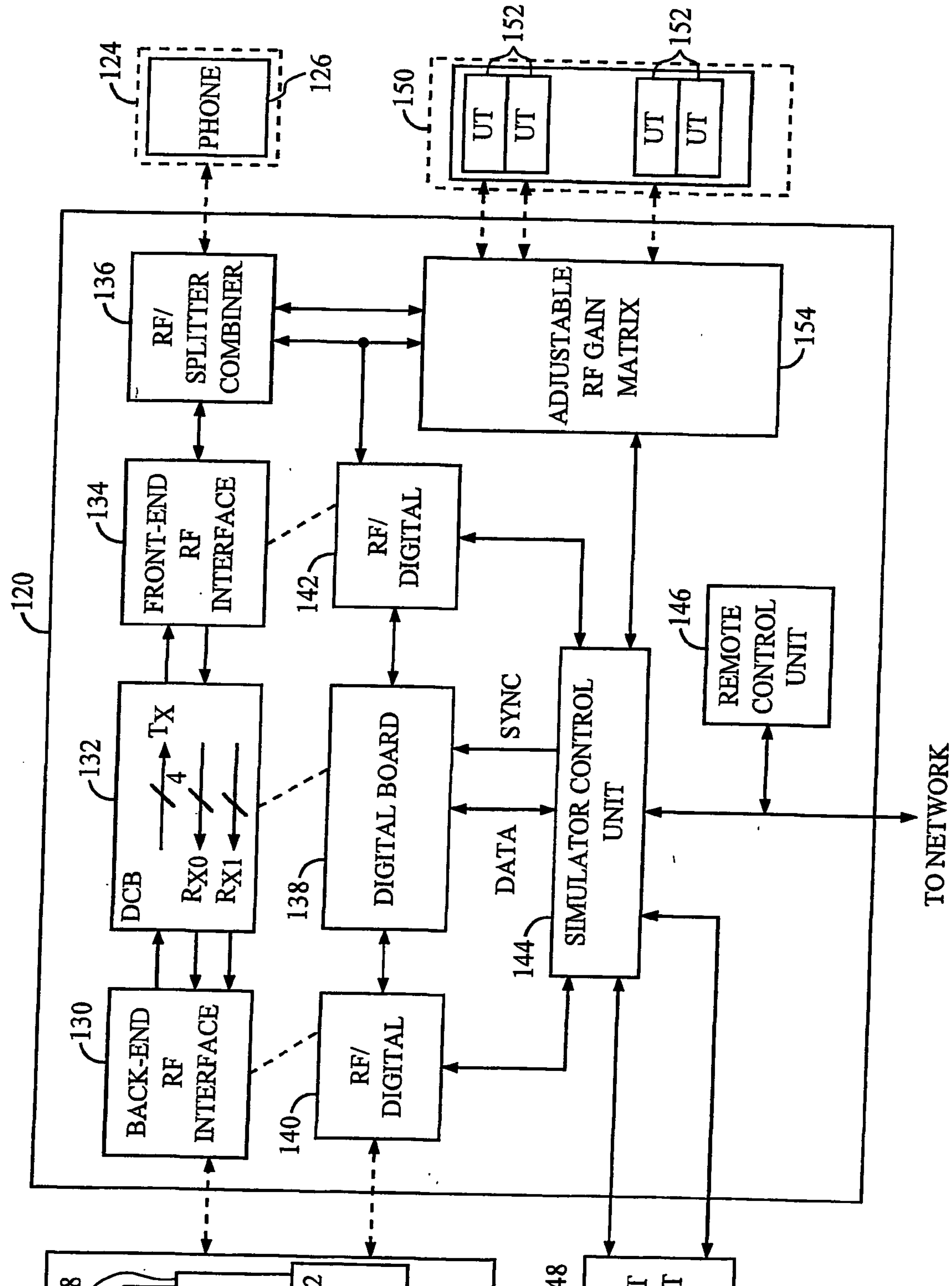
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CONTROL
UNIT
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DCB
Tx
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Rx0
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BSC/BTS
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TEST
EQPT

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/23946

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04Q7/36 H04B17/00 H04B7/185

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04Q H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 937 004 A (FASULO II ALBERT JOSEPH ET AL) 10 August 1999 (1999-08-10) abstract column 2, line 6-53 column 6, line 30 -column 7, line 17 column 8, line 22-40 figures 5,6 claims ---	1-42
A	US 5 233 628 A (RAPPAPORT THEODORE S ET AL) 3 August 1993 (1993-08-03) abstract column 2, line 15 -column 3, line 16 claims --- -/--	1-42

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
28 November 2000	06/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Dejonghe, O

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/23946

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	BOETTCHER A ET AL: "PERFORMANCE EVALUATION OF CHANNEL-SENSITIVE, STABILIZED MULTIPLE ACCESS SCHEMES FOR LAND-MOBILE SATELLITE SERVICES USING A HYBRID SIMULATION TOOL" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,US,IEEE INC. NEW YORK, vol. 11, no. 3, 1 April 1993 (1993-04-01), pages 443-453, XP000377966 ISSN: 0733-8716 the whole document ---	1-42
A	US 5 862 177 A (HALL ERIK M ET AL) 19 January 1999 (1999-01-19) the whole document -----	1-42

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/23946

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5937004	A	10-08-1999	NONE	
US 5233628	A	03-08-1993	NONE	
US 5862177	A	19-01-1999	NONE	